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Wind energy in China: Current scenario and future perspectives

Xia Changliang *, Song Zhanfeng

Department of Electrical Engineering, Tianjin University, Weijin Road 92, Tianjin 300072, PR China

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ABSTRACT

Wind power in China registered a record level of expansion recently, and has doubled its total capacity every year since 2004. Many experts believe that China will be central to the future of the global wind energy market. Consequently, the growth pattern of wind power in China may be crucial to the further development of the global wind market. This paper firstly presented an overview of wind energy potential in China and reviewed the national wind power development course in detail. Based on the installed wind capacity in China over the past 18 years and the technical potential of wind energy resources, the growth pattern was modeled in this study for the purpose of prospect analysis, in order to obtain projections concerning the development potential. The future perspectives of wind energy development in China are predicted and analyzed. This study provides a comprehensive overview of the current status of wind power in China and some insights into the prospects of China's wind power market, which is emerging as a new superpower in the global wind industry.

Contents

1. Introduction

Meeting rising energy demand and safeguarding security of energy supply are the main challenges our world is facing in the 21st century. Together with strong economic growth, China's demand for energy is surging rapidly. Recently, China surpassed Japan to become the second-largest consumer of energy and will overtake the US to become the world's largest energy consumer soon after 2010 [1]. Furthermore, the primary energy demand in China is projected to more than double from 2005 to 2030, according to International Energy Agency (IEA) [2]. Nevertheless, as for per capita energy resources, coal, oil and natural gas in China only reach 55.4%, 11.1% and 4.3% of world average level, respectively [3]. Under this energy background, from a long-term point of view, the increasing energy demand and insufficiency of energy resources will become the major constraints on the economic development in China.

Moreover, reliance on outside energy supplies is increasing in this country. Though China, the leading global consumer of coal, possesses the second-largest coal reserves in the world, distribution difficulties make importing a more attractive alternative in many parts of this country. Consequently, China has shrunk from its historical role as a coal exporter in recent years, becoming a net coal importer in the first half of 2007, and its imports are expected to grow in the future [4]. With regard to crude oil, constituting 20.4% of the country's total energy consumption in 2006, 47% of its demand was met by imports during 2006, 4.1% higher than in 2005, and this figure is expected to rise further to 48.3% in 2008

* Corresponding author. Tel.: +86 22 27403467; fax: +86 22 27402325.
E-mail address: motor_tju@hotmail.com (X. Changliang).

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[5,6]. More generally, China is one of the largest energy consumers, relying heavily on oil and coal imports. Security of energy supply as well as an increasing energy demand has compelled the Chinese government to turn to renewable energy.

As one of the most proven sources of economical renewable energy, wind power can be used to help tackle the above problems. Unlike the conventional energy sources, wind energy is fuel-free, indigenous and sufficient to cope with the ever-growing electricity demand. Moreover, increasing costs of electricity from non-renewable sources will make wind energy more competitive. As policy makers become more aware of this reality, most countries around the world have begun pushing hard on its development. Wind industry today is becoming one of the world's fastest growing energy sectors, helping to satisfy global energy demands and offering the best opportunity to unlock a new era of environmental protection and to start the transition to a global economy based on sustainable energy.

2. Global status of wind energy

Between 1996 and 2006, global wind power capacity grew at an average cumulative rate of 28.6%. The increase in the rate of annual installation was an average of 29.2%. From just 6100 MW in 1996, the world total multiplied more than 12-fold in the following 10 years to have reached over 74,000 MW by the end of 2006. During 2007 alone, close to 19,000 MW of new capacity was added to the electricity grid worldwide, representing a turbine business sector worth approximately 25bn EUR or 36bn US$ [7]. By the end of 2007, the capacity of wind energy installed globally had reached a level of almost 94,000 MW. This is an increase of 31% compared with the 2006 market, showing an overall increase of about 27% in global installed capacity. Fig. 1 illustrates the growth in cumulative capacity and annual installation of wind energy.

Europe has seen a rapid development of wind power in the last decade, and now it is leading the global market [8]. The total capacity of new wind turbines installed across the European Union last year was 8554 MW, an increase of 935 MW compared with the total in 2006, accounting for 43% of the total installed capacity and 73% of the annual market growth during 2007. This marks the first year in history that wind power additions in Europe exceeded the additions of any other power source [9].

In the Americas, the US market surged by 45%, with its 5244 MW accounting for one-quarter of the global installations in 2007. Installations in the fourth quarter of 2007 alone exceeded the total of 2006, and the United States is on track to overtake Germany as the leader in installed wind power by the end of 2009. The recent exceptional growth in the United States is largely due to an extension of the wind production tax credit under the 2005 Energy Policy Act [10]. Canada, with some of the world's best wind resources, is a promising market. Even though its annual growth shrank to some extent compared with the year of 2006, 386 MW of new capacity was installed in 2007, with the country's total increasing by 26%, reaching 1846 MW [11].

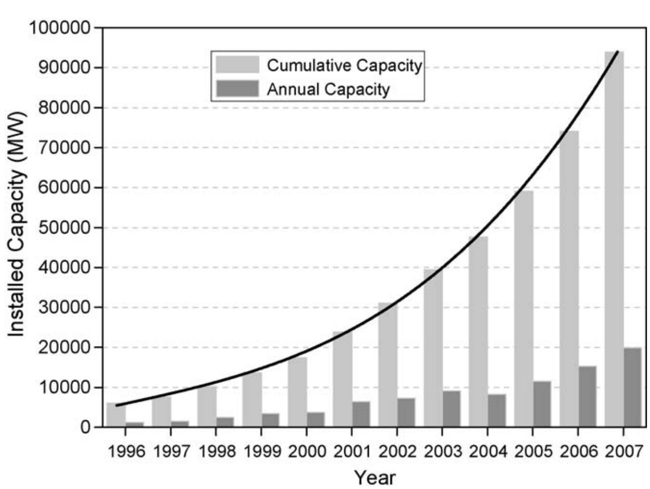

Fig. 1. Installed capacity in world wind power market (1997–2007).

While the market continues a steady drive forward within Europe and America, a major surge of activity has occurred on a global level. New markets are also opening up on other continents. In Pacific Region, New Zealand almost doubled its capacity in 2007 to reach 322 MW, with around 250 MW of projects in the pipeline [12]. In Asia, China has made pronounced leaps in wind power capacity built up, and now it ranks fifth around the world, with 5906 MW by the end of 2007. Indian market has revived strongly after a quiet period in the late 1990s, resulting from the great stability injected by the government. During 2007, almost 1600 MW was installed, resulting in a total of up to 7845 MW. Japan also registered an improved performance during the recent period, reaching a total of 1538 MW. With regard to Africa, there has been development in Morocco with 124 MW installed and a national action plan to install 600 MW by 2010. Egypt, the most successful country in Africa, has constructed several large wind farms on the Gulf of Suez with the support of European government aid agencies. From a current level of 310 MW, the Egyptian government is looking for the country to install 850 MW by 2010.

According to Global Wind Energy Council (GWEC), wind energy today is becoming a global business, with its installations in over 70 countries and its role gradually expanding in global energy supply. However, the current global wind power market is mainly limited to a minority of countries. Over 60% of the global market in 2007 was created by three countries—the USA (26%), Spain (18%) and China (17%). 58% of the entire wind energy installed in the world is located in only three countries—Germany (24%), the USA (18%) and Spain (16%).

3. Wind energy potential in China

With large land mass and long coastline, China has relatively abundant wind resources. According to the estimates by China Meteorological Administration, based on the relatively low height of 10 m above ground, the theoretically exploitable wind resource represents a potential power generation capacity of 4350 GW, and the technically exploitable wind resource 297 GW [13]. In 2007, the national research showed that the onshore technically feasible wind resource is totally around 1000 GW [14]. In addition to that, the offshore potential is estimated at around 300 GW. Figs. 2 and 3 provide an overview of the distribution of wind energy resources in China [15]. Table 1 indicates the wind resource coverage in China [15].

As shown in Figs. 2 and 3, areas with the greatest wind energy potential are within a 200 km-wide region in north China, called "Sanbei Region" ("Three-North Region"), covering Heilongjiang, Jilin, Liaoning, Hebei, Inner Mongolia, Xinjiang and Hexi Corridor of Gansu Province. The wind power density there ranges from 200 W/m^2 to 300 W/m^2, and even reaches 500 W/m^2 in the Ala Mountains, Dabancheng, Huitengxile, Huitengliang of Xilinhaote and the hunting ground of Chengde. Wind power can reach over 5000 h there, and even exceed 7000 h in some sites.

Abundant wind resources are also distributed in the south-east coast and nearby islands. This region includes Shanghai and the provinces of Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi and Hainan. The annual wind power density reaches above 200 W/m^2 within the areas 10 km from the coast, and over 500 W/m^2 on the adjacent islands, such as Tai Mountain, Pingtan,

Table 1
Wind resource coverage in China (*source*: [15]).

Wind power density (W/m^2)	Total annual hours[a] (h)	Total annual hours[b] (h)	Area percentage (%)
>200	>5000	>2200	8
200–150	5000–4000	2200–1500	18
150–50	4000–2000	1500–350	50
<50	<2000	<350	24

[a] Wind speed $\geq$3 m/s.
[b] Wind speed $\geq$6 m/s.

Dongshan, Nanlu, Dachen, Shengsi, Nanao, Mazu, Magong and Dongsha. The wind resources in other regions inland are relatively limited compared with the two regions described above, with the general wind power density below 100 W/m^2. However, influenced by lakes or other particular geographic conditions, certain areas in the interior of China also have considerable wind energy potential, such as the vicinity of Poyang Lake, Jiugong Mountain and Lichuan in Hubei Province.

There are excellent wind resources across the country. Nevertheless, the geographical distribution of the wind resource does not fit well with the country's power load profile [16]. South-east coastal regions with a large power load have fewer wind resources, while the northern regions with massive wind energy potential have a relatively smaller demand. This creates difficulties for the economic development of wind power in most of the areas with abundant wind resources far away from the power load centers. In some areas, however, such as Jiangsu, Fujian, Shandong and Guangdong, there are vast offshore resources located close to the centers of power demand. With its technological and economic maturity, offshore wind energy will play an importance role in the power sector of these areas.

4. Current scenario of wind energy development in China

With massive wind resources and growing concerns over energy supply, China has chosen wind power as an important alternative source in order to rebalance energy mix and ensure energy security. China's government is currently on the way consistently to minimize the barriers to wind energy development and to establish a stable long-term supporting mechanism. Wind power market in China is therefore boosted by various incentive programs and registered a record level of expansion recently.

4.1. China's support mechanism for wind energy

National and sub-national governments around the world — in both developed and developing countries — are placing considerable faith in wind energy as an important and effective power technology for sustainable energy supply, and therefore providing particularly strong support to promote its development. Many countries have launched national support programs and set ambitious targets. Different incentive measures and policies have been adopted to attain such targets. The most common models for market stimulation include public funds for R&D programs, direct support of investment cost, establishment of a premium price of electricity from wind turbines, obligations for utilities to purchase wind-generated electricity and provision of tax allowance. These strategies are the basis for the successful exploitation of wind energy. A mixture of those strategies has often been used in some countries, such as Denmark, Germany and Sweden [17,18]. In Denmark, for instance, the incentive package includes a premium price for electricity, a grant towards investment cost and some tax allowances [19].

Like most European countries, China has stipulated a series of incentive policies to encourage its technical innovation, market expansion and commercialization. Political milestones for wind power development in China are shown in Fig. 4. Some of the supportive issues are as follows:

(a) *Ride the Wind Program*: With the aim of importing technology from foreign companies and establishing a high-quality Chinese wind turbine generator sector, the former State Development and Planning Commission (SDPC) initiated the

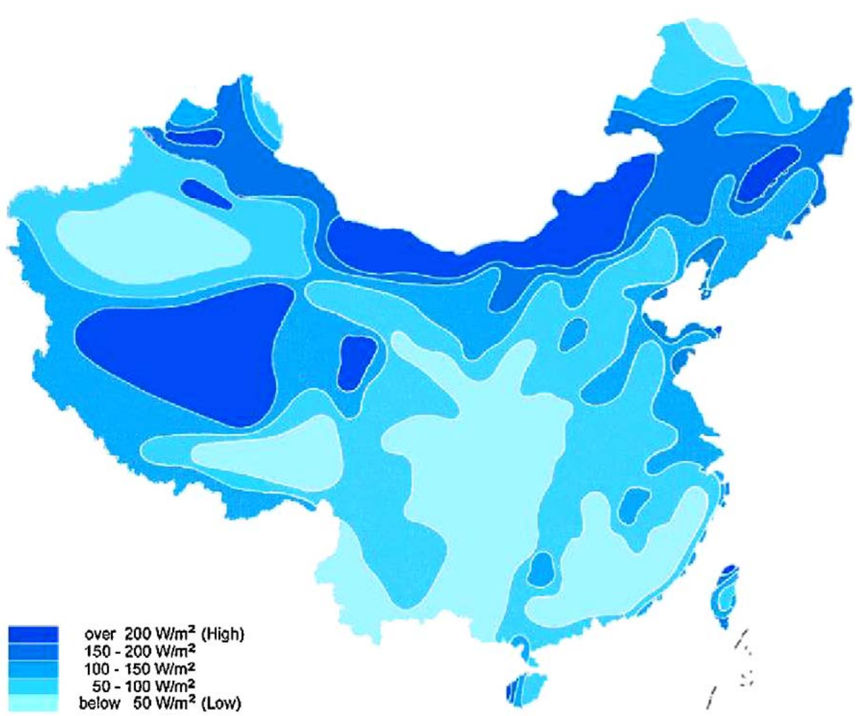

Fig. 2. Wind density map of China (*source*: [15]).

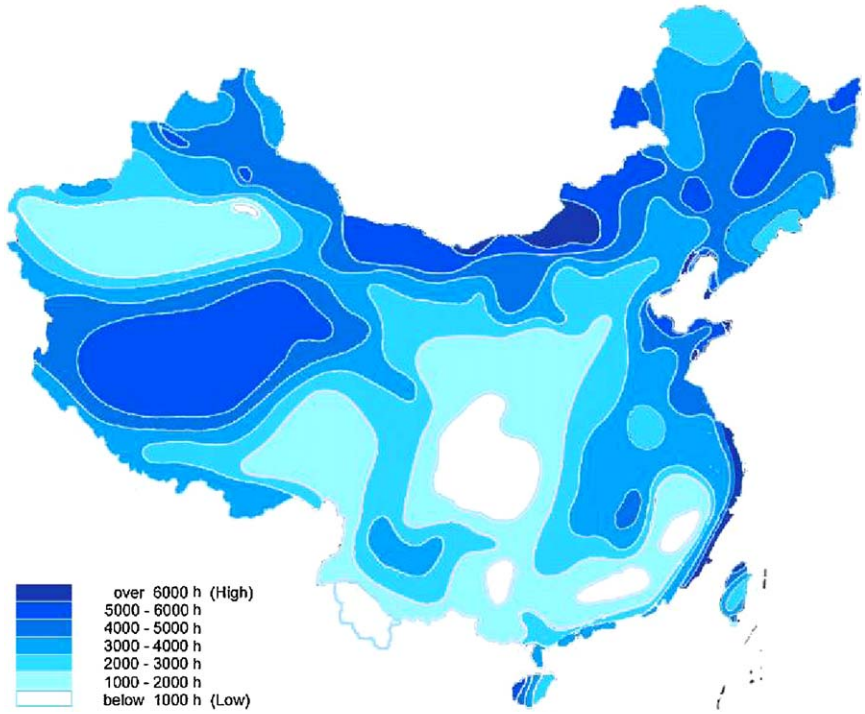

Fig. 3. Hours with wind speed over 3 m/s in different areas (*source*: [15]).

"Ride the Wind Program" in March, 1996. Wind farm projects approved by SDPC during the Ninth Five-Year Plan (1996–2000) required that wind turbine generator equipment purchased for those projects contain locally made components, which account for at least 40% of the total [20]. This initiative led to the formation of joint ventures in the Chinese market and effectively introduced wind turbine generator manufacturing technology into China.

(b) *National Debt Wind Power Program*: To encourage the development of domestic wind power equipment manufacturing, the former State Economic and Trade Commission (SETC) implemented the "National Debt Wind Power Program" to use national debt with favorable interest subsidy conditions to build wind farms with locally manufactured wind power components for new generation projects. By 2000, this program had established four pilot projects with a total installed capacity of 73 MW [21]. Thus far, this program has been completed.

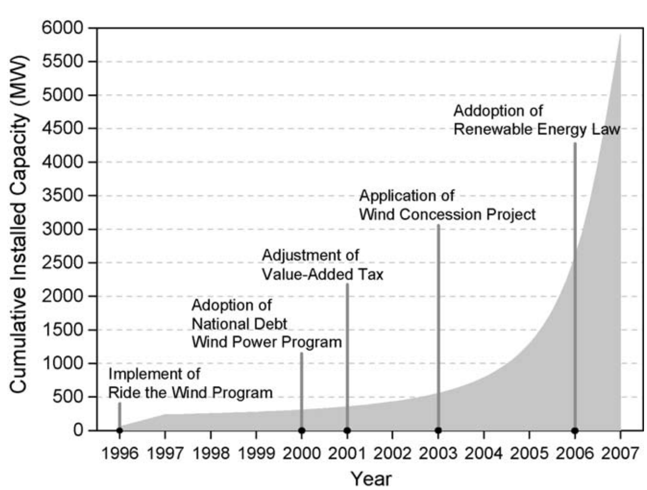

Fig. 4. Political milestones for wind power development in China.

(c) *Wind Power Concession Project*: In order to promote the commercialization of wind power, the National Development and Reform Commission (NDRC) adopted the concession approach in 2003 with a 20-year operational period, which have been used relatively successfully for the exploration and development in China's petroleum and natural gas sectors. Through the Wind Power Concession Project, the Chinese government hopes to create further incentives for international and domestic investors to develop large-scale wind farms and to encourage a reduction in the price of wind power within China's reformed electricity industry. The basic approach is to select potential projects of relatively large scale (100 MW), and to choose the investor through competitive bidding. The government guarantees that the on-grid power price will be set through process bidding, and ensures that all electricity generated by the wind farms will be purchased [22]. Under this policy, market risk is reduced significantly, which in turn reduces the risk premium of the internal rate of return for wind power projects. From 2003, NDRC has continuously organized rounds of wind concession projects, giving more emphasis on the domestic manufacturing. By the end of 2006, four rounds had raised 15 wind concession projects with a total capacity of 2550 MW. All the projects have started construction, only 25% of which have been completed.

(d) *Renewable Energy Law*: In February 2005, China's Renewable Energy Law was formulated and came into force on January 1, 2006. The law requires that power grid operators purchase a full amount of wind power generated by registered producers. The law also offers financial incentives, such as a national fund to foster renewable energy development and discounted lending and tax preferences for renewable energy projects [23].

Besides, the Chinese government reduced the value-added tax for wind power from 17% to 8.5% in September 2001, and adjusted the import customs tariff rate of wind turbine generator sets to 5% and that of its components to 1% in 2007 [24,25]. Some local governments in Guangdong, Jilin, Xinjiang and Inner Mongolia also formulated their own incentive policies to develop wind power. Most recently,

the wind energy market in China has been significantly boosted as a result of these effective measures. With substantial cost reductions and rapid market expansion, China will become a new leader in the world market in the near future and make greater contributions to the global development of wind energy.

4.2. Wind power growth in China

In the early 1970s, China began to develop wind energy with a primary purpose of supplying electricity to people living in the remote areas without electricity grid connection, such as herdsmen and residents in remote pastoral areas or isolated islands. The development of grid-connected wind power started from the late 1980s, along with the building of the first wind farm of three 55 kW wind turbines in Rongcheng County, Shandong Province, in 1986, which used equipment imported from Vestas, Denmark. In the year of 1989, two pilot projects with 13 bonus 150 kW wind turbines and five 100 kW wind turbines were established in Xinjiang Province and Inner Mongolia, respectively [26]. These projects, together with extremely favorable financial backing from the government, created the conditions for the demonstration stage of the national wind energy market. Wind farms began to be built throughout the country, mainly using imported wind turbines.

In 1994, the former Ministry of Electric Power issued regulations covering grid connection and the payment for electricity generated, with the purpose of making wind power commercially viable. As the security of investors was guaranteed, impressive gains were registered in the wind energy market during 1994 and 1997. Especially in 1997, China saw the doubling of the annual market, with the new installation of 91 MW larger than the total wind power by the end of 1996, showing a market growth of 115%. By the December of 1998, 515 wind electric generators had been established, with an aggregate capacity of 224 MW and a maximum unit capacity of 600 kW [27]. In Dabancheng (Xinjiang Province), Nanao (Guangdong Province), Donggang (Liaoning Province) and Huitenxile (Inner Mongolia), wind farms with a capacity of over 10 MW were built up, respectively. Nevertheless, with the reform of the electricity supply system and its transformation into a competitive market, the wind power industry developed slowly in the following years, due to its high cost and vague policy support. By the end of 2000, the installed capacity across the country had only reached 344 MW, with a great distance to the national target of 1 GW set by the former Ministry of Electric Power in 1995 [28].

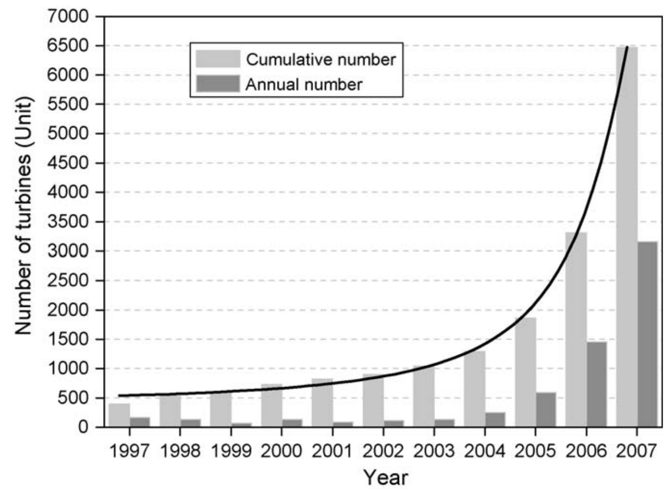

Fig. 6. Number of installed turbines in China wind power market (1997–2007).

In the year of 2003, NDRC initiated the "Wind Power Concession Project", aiming to promote large-scale commercial wind power development. By means of selecting investors and developers of wind power projects through bidding, this incentive had increased the domestic manufacturing capacity and expanded the total capacity from just 567 MW in 2003 to 1260 MW by the end of 2005. In order to further promote the development of renewable energy, the National People's Congress of China issued Renewable Energy Law and its detailed incentive policies, providing a boost to renewable energy in China. Subsequently, the wind industry has moved into a rapid growth phase.

Figs. 5–7 illustrate the installed capacity, number of installed turbines and average capacity per unit in China wind power market. According to GWEC, China has become the world's fastest growing wind energy market, with an average annual growth rate of 56% in the past 7 years. The country now ranks fifth in the world wind power market following Germany, the US, Spain and India. The installed capacity of wind power in China has reached 5906 MW by December 2007. A total number of 6469 wind turbines are distributed in 158 wind farms, feeding about 52bn kWh of wind power into the grid in 2007 alone. The capacity of most generators installed ranges from 600 kW to 2 MW, which account for 95% of the total. By August 2008, there have been 235 Chinese wind energy projects in the "Clean Development Mechanism (CDM) pipeline", with a total capacity of 11,932 MW

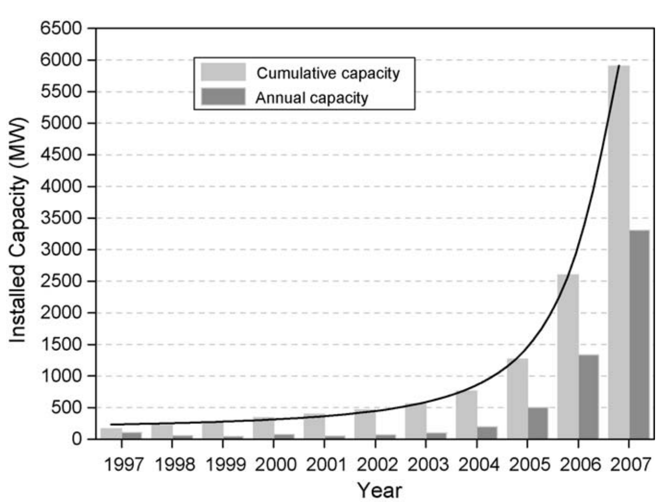

Fig. 5. Installed capacity in China wind power market (1997–2007).

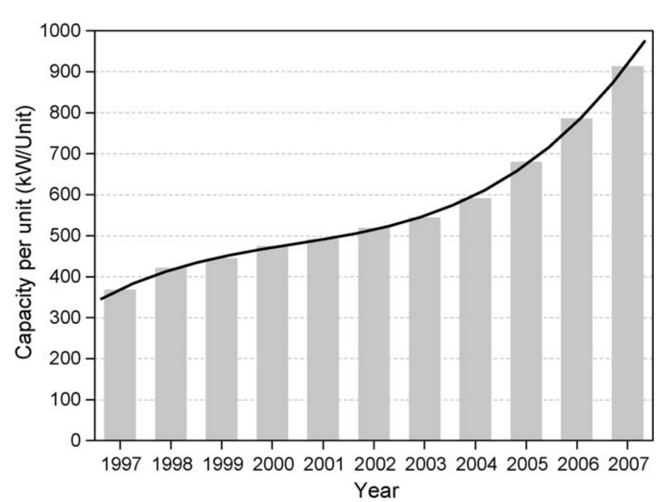

Fig. 7. Average capacity per unit in China wind power market (1997–2007).

Table 2
Province wise cumulative installed wind power capacity in China (December 31, 2007; *source*: [30]).

Index	Province (Municipality, Aut. Region)	Total units	Cumulative capacity (kW)
1	Inner Mongolia	1736	1,563,190
2	Jilin	624	612,260
3	Liaoning	621	515,310
4	Hebei	514	491,450
5	Heilongjiang	430	408,250
6	Ningxia	384	355,200
7	Shandong	315	350,200
8	Gansu	428	338,300
9	Xinjiang	418	399,310
10	Jiangsu	188	293,750
11	Guangdong	471	287,390
10	Others	340	291,750
	Total	6469	5,906,360

[29]. As for the province wise installation, Inner Mongolia, Jilin, Liaoning, Hebei and Heilongjiang have experienced the fastest development, accounting for over 60% of cumulative installed wind power in China, as shown in Table 2 [30]. Inner Mongolia Autonomous Region has contributed over 1563 MW, about one-quarter of the total installed capacity of China. The largest installation of wind turbines in the country so far has been in Wulanchabu area near Hohhot in Inner Mongolia. The aggregate capacity of this area is over 382 MW.

Onshore wind energy in China is developing at a healthy rate, while offshore wind power installation is progressing slowly, partly due to higher costs and maintenance concerns compared with the booming onshore markets. There are no commercial offshore wind farms in China at this stage, although demonstration projects are ongoing more recently. The first pilot project, with one 1.5 MW wind turbine installed upon jacket at the Suizhong 36-1 oil field in Bohai Bay, was linked to the national grid in November 2007 [31], and offshore construction work has started on three other sites, which are Shanghai Donghai Bridge, Dongtai and Rudong.

On August 31, 2007, NDRC issued "National Middle and Long-term Plan for Renewable Energy Development". According to the plan, by 2010, about 30 100 MW-scale wind farms will have been established and three 1 GW-scale wind farm bases built up in Jiangsu, Hebei and Inner Mongolia, respectively. In addition, the plan also sets the target of reaching a total installed wind capacity of 30 GW and 1 GW offshore wind capacity by 2020. Many analysts believe that more aggressive targets could be reached [32,33].

5. Future perspectives of wind energy in China

The growth rate of installed wind capacity is relatively slow in the preliminary stage, and a rapid growth will be realized when the technology is fully commercialized. The growth will then come close to the maximum and the newly built wind power generators will gradually decline after a certain period. This process can be clearly observed in the development of wind power in Denmark, and the future trend prediction of wind power in Germany, as demonstrated in Figs. 8 and 9 [34]. Such a pattern is similar to an s-curve and follows the natural growth trend.

This process can be traced by the logistic growth function, a general approach which can describe such a phenomenon: in the beginning stage, the growth rate is slow, and then it gradually accelerates; after reaching a peak, it begins to slow down; finally the growth rate is close to zero. During the last three decades researchers have illustrated in various studies that quite different processes such as diffusion of innovation goods, new technologies and power forms, creativity, population dynamics and product sales can be modeled using the s-shaped logistic curves [35–37]. In this article, the logistic development pattern is also adopted to model onshore wind power growth in China.

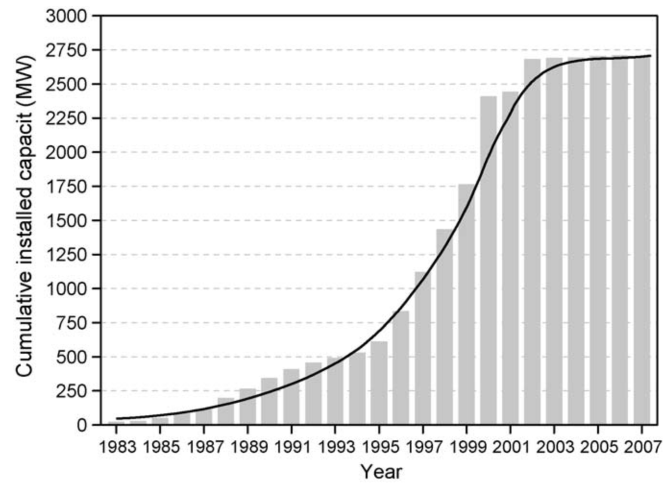

Fig. 8. Development of onshore wind power in Denmark (1983–2007).

The logistic model can be expressed as the following ordinary differential equation:

$$\frac{\mathrm{d}}{\mathrm{d}t}V(t) = aV(t)\left(1 - \frac{V(t)}{N}\right) \tag{1}$$

$$V(t) = \frac{N}{1 + be^{-at}} \tag{2}$$

where $V(t)$ is the installed capacity of wind power over time t; N is the technical potential of wind power, showing how large the capacity $V(t)$ will become; b is the initial coefficient; a is the velocity of growth.

As indicated above, on one hand, the newly built installed wind power is proportional to the scale of existing capacity; on the other hand, it is also inversely proportional to the exploitation degree. Consequently, the logistic model reflects not only the trend of the accelerated rate due to the increasing scale of wind power and the maturation of technology but also the fact that the development will gradually slow down as the quantity reaches the maximum.

Based on the historical data of installed capacity of wind power from 1990 to 2007, with 1990 as the base year ($t = 0$), N equaling

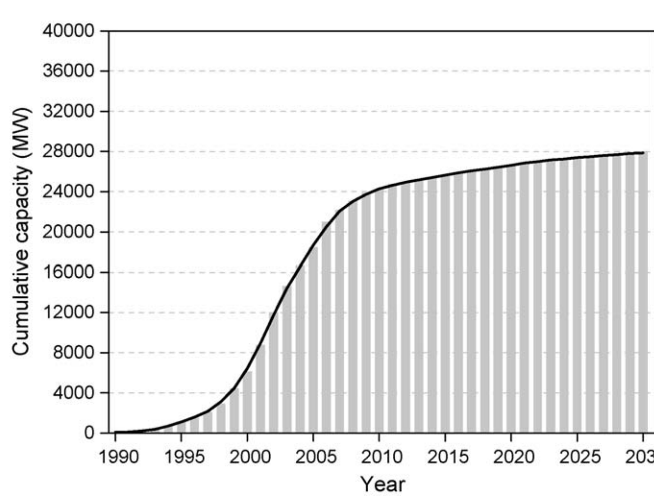

Fig. 9. Status and prospect of onshore wind power in Germany (1990–2030, *source*: [34]).

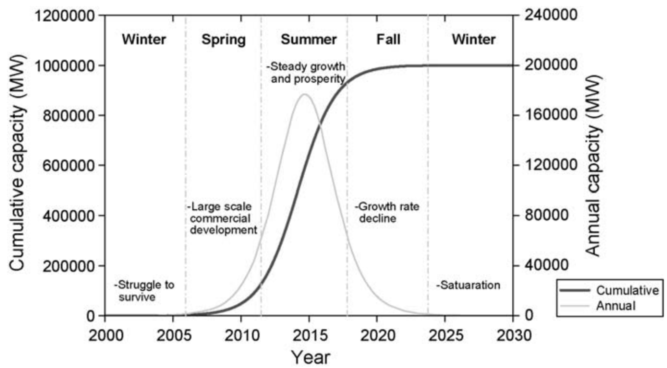

Fig. 10. Installation capacity of onshore wind power in China with respect to time scale.

the technical potential of onshore wind power in China, the least-squares method is used for the regression of formulae (1) and (2) to estimate the coefficients *a* and *b*. Their values are equal to 3.329×10^7 and 0.7162, respectively. The produced logistic curve fits well with the actual data and this is further supported by the *R*-squared coefficient of determination which is 0.9821. Therefore, the regression result is acceptable in high confidence with *t*-test significantly. It should be noted that the factors for the newly built wind power capacity are very complex, which are mainly related to the resource constraints, technology development and competitiveness to coal generation, and the latter two factors are not considered in the current model. In fact, with increased research and development, conversion technologies might be improved and technical potential increased.

Fig. 10 shows the results of the installation capacity of wind power with respect to time scale. In this paper, the seasons as a metaphor are adopted to describe in a friendlier manner the differences and special attributes of the successive periods of growth, saturation, and decline in an s-curve [38], as indicated in Fig. 10. A developing life cycle in this curve is divided into five equal duration seasons: winter, spring, summer, fall and winter again.

Winter is a difficult season of low growth when wind power in China struggles to survive and prevail. During this period, due to the country's substantial coal resources and the still relatively low cost of coal-fired generation, cost reduction of wind power in China proceeded slowly. On the manufacturing side, despite the increasing involvement of new domestic players, such as Goldwind and Sinovel, most of the Chinese manufacturers have been using European or US technology as the basis for their designs, and the Chinese market was dominated by imported wind turbines from Vestas, Gamesa, General Electric, Suzlon and Nordex. Although there remain barriers to wind energy development in China, winter is also a period of pregnancy. The China's government has already taken considerable steps in the right direction, and is now on the way consistently to minimize these barriers and establish a stable long-term supporting mechanism.

The wind power market in China is currently at the beginning of spring. The future looks bright and the market will continue to develop at an ever-expanding rate foreseen for the next several years. Based on the supporting schemes issued by the government, there will be a high degree of innovation in the domestic market to deliver high-quality and high-reliability technology, leading the domestic wind power industry to large-scale commercial development. The subsequent increasing installation could bring the cost of wind power down closer to that of coal, especially in the climate of rising coal prices. During this phase, the country will emerge as a global leader in terms of wind power generation and equipment manufacturing.

After the rapid growth at accelerating rates in the spring phase, wind power development in China will enter summer, a period of steady growth and prosperity, when the market harvests the fruits of innovations and investments of previous years. The peak point of growth rate will occur around 2015. After the developing process approaches 2016, growth, although always present, begins to decelerate, signaling the emergence of fall after 2018. Then the growth trend gradually comes to saturation as the installation capacity reaches the upper limit of technical potential, and then another winter is drawing near.

More generally, as time goes by, onshore wind power in China undergoes struggle to survive and preparation of legislative framework during winter, to accelerating growth during spring, to extreme profitability and perfection in summer, to gradual deceleration of growth and saturation at fall, and finally when the installation capacity approaches the maximum point, the market then enters another winter. As is demonstrated in the growth trend, wind power in china follows a growth curve with a cycle of approximately 30 years, towards a considerably higher level of more than four times the recent installation level. According to Modis, logistic growth often proceeds in successive s-curves [39]. One of the best candidates to be the most important pole in the following trend is "repowering" in the onshore wind energy market. Repowering, the replacement of first-generation wind turbines with modern ones, could use the existing sites more productively by increasing their installed capacities and accelerate the replacement process so that plants are dismantled before their technical life spans are over. With new impetus injected by repowering, a sufficiently large and stable domestic market can be secured despite the ever-decreasing potential for new wind turbine installation [40,41]. However, this following new trend might not be confirmed or quantified until the new growth process to emerge and additional data to be summoned.

As for the offshore market in China, its development is in the initial demonstration period or in the phase of winter. Such a market currently shows no commercial capacity; furthermore, the domestic wind industry cannot provide the technological basis. Although China is expected to follow the general trend in Europe and promote large-scale development of offshore wind energy, this is unlikely to happen any sooner than from 2010 onwards, when one or two 100 MW-scale pilot offshore wind projects are planned to be set up. There is a long way to go to overcome various technological and regulatory barriers and eventually to deliver significant offshore wind capacity into China's energy mix. However, the development of China offshore wind power will follow a more expedient mode, based on the onshore experiences which will pave the way for the offshore market to rapidly unlock the massive offshore wind resources existing around the county.

During the development of wind power in China, government policy has been an important factor in influencing its market growth. As indicated in the previous analysis, wind power market in China is still young and its further development heavily relies on an enabling pricing and a regulatory and fiscal environment. In the past several years, China's national and provincial governments have both developed supportive frameworks in order to drive down costs and speed up the broad introduction of wind energy technologies [42–44]. In 2005, the National People's Congress of China issued the Renewable Energy Law, which is regarded as an important political milestone for wind power development in China. This law led to the establishment of a feed-in tariff for renewable power, which requires utilities to purchase all renewable power generated at attractive fixed rates, and mechanisms for allocating the incremental costs of renewable energy nationwide, preventing incremental costs from being borne exclusively by consumers adjacent to renewable energy generation facilities [25,45,46]. More recently, relative regulations and incentives were

launched, including special fund management, mandatory market share programs, and renewable energy pricing regulations [47–49]. These recent renewable energy laws and relative measures are of proven effectiveness to help overcome the barriers to wind power development and accelerate the commercialization of wind energy technologies in China. On the basis of these previous preparations, supporting mechanism with a clear policy direction has currently been set up in China, enabling a more rapid development of wind energy, encouraging sustained investment and technology improvement and resulting in positive long-term impacts on the wind power development in China.

6. Conclusion

China is experiencing rapid economic growth with resulting high energy consumption requirements. A heavy dependence on energy import and an increasing energy demand lead the Chinese government to turning to renewable energies. Today, wind power in China now receives particularly strong government support and has made pronounced leaps in installation capacity, with an average annual growth rate of over 50% in the past several years. The installation had reached 5906 MW by the end of 2007, ranking fifth around the world. Based on the review of the wind energy development in China and the historical installation data, this paper analyzed its future growth pattern regarding the technical potential and variation of growth rate.

It is demonstrated that after years of development, onshore wind power market in China, seen as a key market globally, is currently at the beginning of rapid development. Its near future looks bright and the market will continue to develop at an ever-expanding rate foreseen for the next several years. China's wind industry will emerge from its dynamic local markets to become a new superpower in the global market. However, its growth rate will probably reach its peak point at around 2015. Since then, although the installed wind capacity in China will still increase at a rapid pace, gradual deceleration of growth will begin, signaling the end of stable and sustained expansion. During 2020 and 2025, as the installation capacity reaches the upper limit of technical potential, the growth trend will gradually come to saturation.

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References

[1] U.S.–China economic engagement: key mechanisms, opportunities and challenges; March 19, 2008. Available online at <http://www.state.gov> [accessed September 2008].
[2] International Energy Agency. World energy outlook 2007: Fact sheet—China; 2007.
[3] Bao XH. Energy science and technology: the Chinese perspective; November 15, 2005. Available online at <http://www.iea.org> [accessed September 2008].
[4] China first-half coal imports hit 27.07 million tons; July 31, 2007. Available online at <http://www.chinamining.org> [accessed September 2008].
[5] National Bureau of Statistics of China. China statistical yearbook 2007; 2008.
[6] Analysis of oil import in China; September 08, 2008. Available online at <http://post.cnfol.com> [accessed September 2008].
[7] Angelika P. US, China & Spain lead world wind power market in 2007; February 06, 2008. Available online at <http://www.awea.org> [accessed September 2008].
[8] European Wind Energy Association. Delivering energy and climate solutions-EWEA 2007 annual report; 2008.
[9] Wind energy leads EU power installations in 2007, but national growth is inconsistent; February 04, 2008. Available online at <http://www.ewea.org> [accessed September 2008].
[10] United States Congress. Energy policy act of 2005; 2005.
[11] Canadian Wind Energy Association. Wind energy sets global growth record in 2007; February 01, 2008. Available online at <http://www.canwea.ca> [accessed September 2008].
[12] Global Wind Energy Council. Global wind 2007 report; 2008.
[13] China Meteorology Bureau. China wind resource assessment report; 2006.
[14] Weng SL. Technical feasible wind resource exceeds 1,000 GW in China; April 23, 2008. Available online at <http://www.newenergy.org.cn> [accessed September 2008].
[15] Distribution of China's wind energy resources. Available online at <http://www.newenergy.org.cn> [accessed September 2008].
[16] Li JF, Gao H, Shi PF, Shi JL, Ma LJ, Tai HY, et al. China wind power report 2007. Beijing: China Environmental Science Press; 2007.
[17] Patrik S, Kristina E, Maria P. Wind power development in Sweden: global policies and local obstacles 2007;11:365–400.
[18] Wind energy in Germany. Available online at <http://www.wind-energie.de> [accessed September 2008].
[19] Paolo A. Wind electricity in Denmark: a survey of policies, their effectiveness and factors motivating their introduction 2007;11:951–63.
[20] State Development and Planning Commission. Ride the wind program; 1996.
[21] National Renewable Energy Laboratory. Renewable energy in China: grid connected wind power in China; April, 2004. Available online at <http://www.nrel.gov> [accessed September 2008].
[22] Shi JL. Demonstration of wind power concession policy to reduce the large-scale wind power price; January 05, 2007. Available online at <http://www.apfed.net> [accessed September 2008].
[23] The Central People's Government of the People's Republic of China. Renewable energy law of the People's Republic of China; 2006.
[24] Ministry of Finance People's Republic of China. Adjustment of value-added tax for some resource comprehensive utilization products; 2001.
[25] General Administration of Customs of People's Republic of China. Customs tariff of import and export of the People's Republic of China; 2007.
[26] He DX. Current situation of wind energy in China. Sol Energy 1999;4:16–8.
[27] China Wind Energy Association. Status and development of China wind industry; May 16, 2006. Available online at <http://www.crein.org.cn> [accessed September 2008].
[28] Focus on 20-year industrialization development of wind power market in China; February 09, 2007. Available online at <http://www.cps800.com> [accessed September 2008].
[29] UNEP Risoe Center. CDM projects grouped in types; September 01, 2008. Available online at <http://www.cdmpipeline.org> [accessed September 2008].
[30] Shi PF. Statistics of wind energy installations in China during 2007; February 28, 2008. Available online at <http://www.cwea.org.cn> [accessed September 2008].
[31] The first offshore wind turbine has been erected and connected to the national grid; January 25, 2008. Available online at <http://www.cwea.org.cn> [accessed September 2008].
[32] National Development and Reform Commission. Middle and long-term program of renewable energy development; 2007.
[33] David K. A method for developing geographic–economic wind supply curves: China case study; July 10, 2008. Available online at <http://www.nrel.gov> [accessed September 2008].
[34] Pierre D. Status and perspectives of wind energy; June 20, 2008. Available online at <http://www.german-renewable-energy.com> [accessed September 2008].
[35] Caroline Mabel M, Fernandez E. Growth and future trends of wind energy in India. Renew Sustain Energy Rev 2008;12:1745–57.
[36] Boretos GP. The future of the mobile phone business. Technol Forecast Soc Change 2007;3:331–40.
[37] Marchetti C. Longevity and life expectancy. Technol Forecast Soc Change 1997;3:281–99.
[38] Modis T. Conquering uncertainty. New York: McGraw-Hill; 1998.
[39] Modis T. Fractal aspects of natural growth. Technol Forecast Soc Change 1994;1:63–73.
[40] Repowering: potentials and framework conditions in Germany and Denmark and new markets for second-hand wind turbines; 2005. Available online at <http://www.afriwea.org> [accessed September 2008].
[41] More wind Power with fewer wind turbines; August 2005. Available online at <http://wind-energie.de> [accessed September 2008].
[42] National Development Reform Commission. China national energy strategy and policy to 2020: Scenario analysis on energy demand; 2004.
[43] People's Government of Guangdong Province. A notice on the feed-in tariff of wind power projects; 2004.
[44] People's Government of Guangdong Province. Suggestions on promoting wind power development in Guangdong Province; 2001.
[45] National Development Reform Commission. Management method of renewable energy power generation pricing and cost allocation; 2006.
[46] National Development Reform Commission. Interim procedures of allocating the incremental costs of renewable energy; 2007.

[47] Ministry of Finance People's Republic of, China. Management of special funds for the development of renewable energy 2007.
[48] National Development Reform Commission. Regulations on renewable energy power generation; 2006.
[49] National Development Reform Commission. Suggestions on promoting wind industry development; 2006.

Xia Changliang received the Ph.D. degree from the Institute of Electrical Engineering, Zhejiang University, China in 1995. He is currently a Professor and Head of the Electric Machine and Control System group at Tianjin University. His research covers wind power development and wind turbine control. He has presided more than 20 scientific research projects as the prime principal of the project, and in particular, his research is currently supported by National Science Fund for Distinguished Young Scholars. In 2007, he received Science & Technology Award for Chinese Youth.

Song Zhanfeng received the B.Sc. degree in Electrical Engineering in 2006 from Tianjin University, Tianjin, China, where he is currently pursuing the Ph.D. degree. He worked on projects regarding the wind power market and grid connection of wind power capacity.